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TEXAS ESTUARIES AND WATER RESOURCE DEVELOPMENT PROJECTS[1]

by

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The Gulf coast of Texas is a broad arc of approximately 375 miles, extending from Sabine Pass to the mouth of the Rio Grande. Throughout its much embayed length, this coastline passes through a variety of climatic regions, ranging from the humid zone (55 inches or more of precipitation) of the eastern portion of the semiarid zone (25 inches or less) of southern Texas (Fig. 1).

The embayments, called estuaries, represent ecotones or "buffer zones" between the fresh water of the river systems and the salt water of the sea. As such, estuaries have physical, chemical, and biological characteristics which are unlike those of either the fresh or oceanic waters. They are rich in fauna and, in many instances, represent resources which support major commercial and sport fisheries. Unfortunately, these estuaries are being destroyed or modified by an ever-increasing number of water development and construction projects.

The purposes of this paper are to: (1) outline some of the typical characteristics of estuaries; (2) show the importance of the estuarine fauna to commercial and sport fisheries of the coastal waters of Texas; and (3) describe changes within the estuaries attributable to water development and construction projects.

ESTUARINE CHARACTERISTICS

Several definitions have been proposed for estuaries by various scientists having different professional interests. For our purposes, however, the definitions of Tully and Barber, Ketchum, and Reid are sufficient. Tully and Barber (1961, *In* Mary Sears, Oceanography, *Am. Assoc. Advancement Sci. Publ.* 67, p. 19) state that the basic requirement for the establishment of an estuarine system in any region is the presence of a supply of fresh water which exceeds losses by evaporation or freezing. Ketchum, (1951, *J. Marine Res.* 10(1): 19) and Reid (1961, Ecology of inland waters and estuaries, Reinhold, N. Y., p. 69) both define an estuary as a body of water in which river water mixes with, and measurably dilutes, sea water. Estuaries are also defined as the wide mouth of the river or arm of the sea where the tide meets the river currents, or flows and ebbs.

Estuaries are usually, though not always, semienclosed bodies of water. Hydrological conditions described above are often found far offshore from the mouths of large rivers. Estuaries along the Gulf coast and especially Texas, result from the formation of offshore bars across drowned river mouths, although in other areas they frequently occur in deltaic formations. The shorelines bordering the landward margins of Texas estuaries are usually composed of both Pleistocene and Recent sediments, while the offshore bars usually consist of Recent sediments.

The estuaries (and coastal lagoons) of Texas, covering a total of approximately 1,200 square miles, range in size from about 70 square miles (Sabine Lake) to about 530 square miles (Galveston Bay and adjacent waters). In general, the estuaries are oval or funnel shaped and most have dimensions of less than 15 miles, whereas the coastal lagoons (represented in Texas by the Laguna Madre with an area of approximately 490 square miles) are oblong and parallel the coast. Furthermore, both have cross-sections that reveal shallow, depression shapes frequently transected by oyster reefs or sand bars. Their average depths are usually less than 10 feet. Shepard (1953, *Bull. Am. Assoc. Petroleum Geol.* 37(8): Fig. 1), in a comparison of unpublished soundings of Texas bays made by the U. S. Coast and Geodetic Survey during the years 1854-75 and 1933-35, found that those bays which have rivers that dump large amounts of sediments into them showed considerable shoaling, whereas those having no large rivers emptying into them actually deepened or remained the same.

Data from U. S. Coast and Geodetic Survey Tide Tables indicate that Gulf tides are of small amplitude, generally less than 2 feet. Irregular changes of water level of greater amplitude are generally caused by wind-driven currents. Wind-driven currents are important for maintaining circulation patterns in the estuaries and for

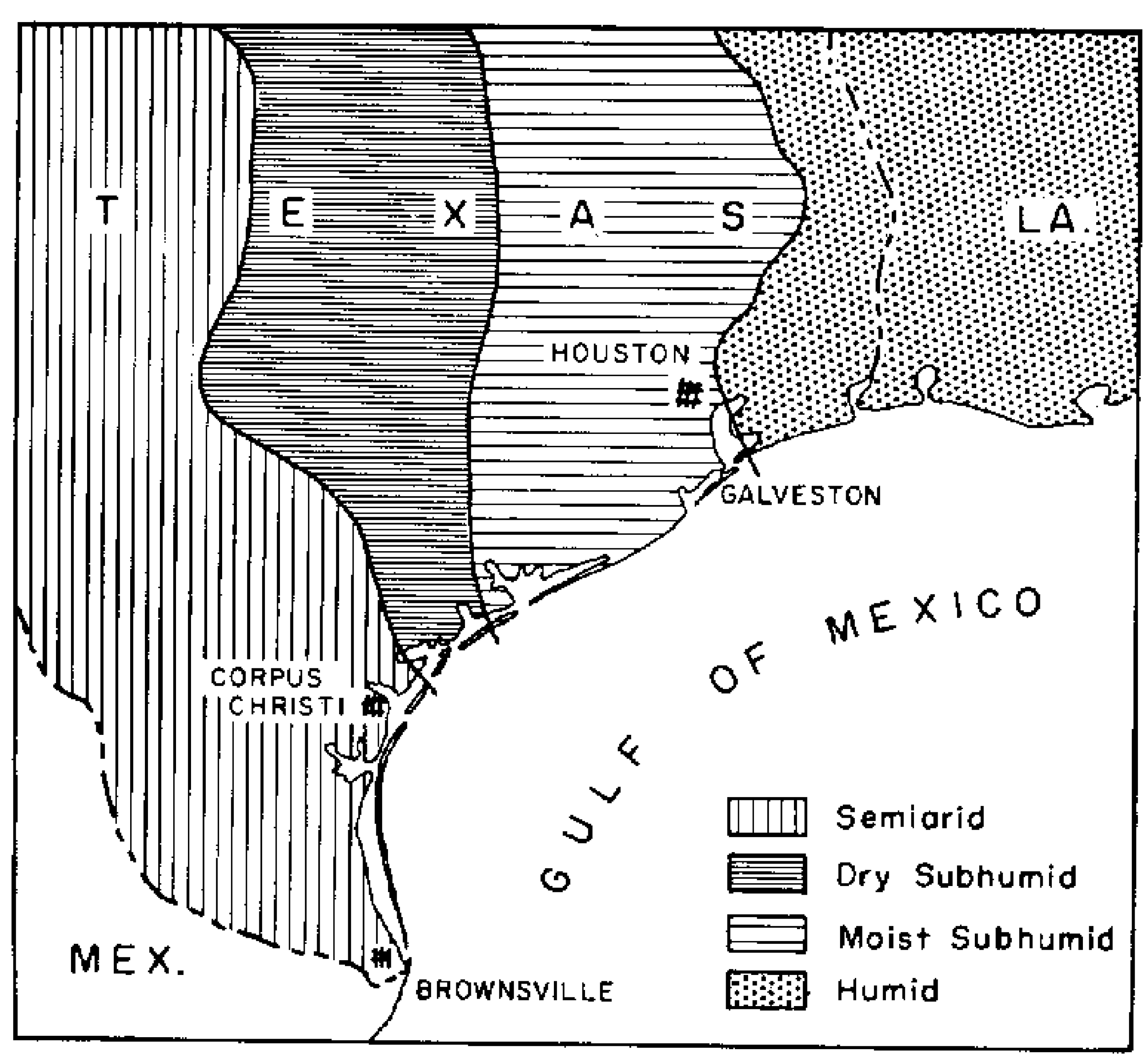

Figure 1. Climatic zones of Texas (Modified after Thornthwaite, 1948, Geogr. Rev. 38(1): Pl. I).

[1]Contribution No. 199, Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas.

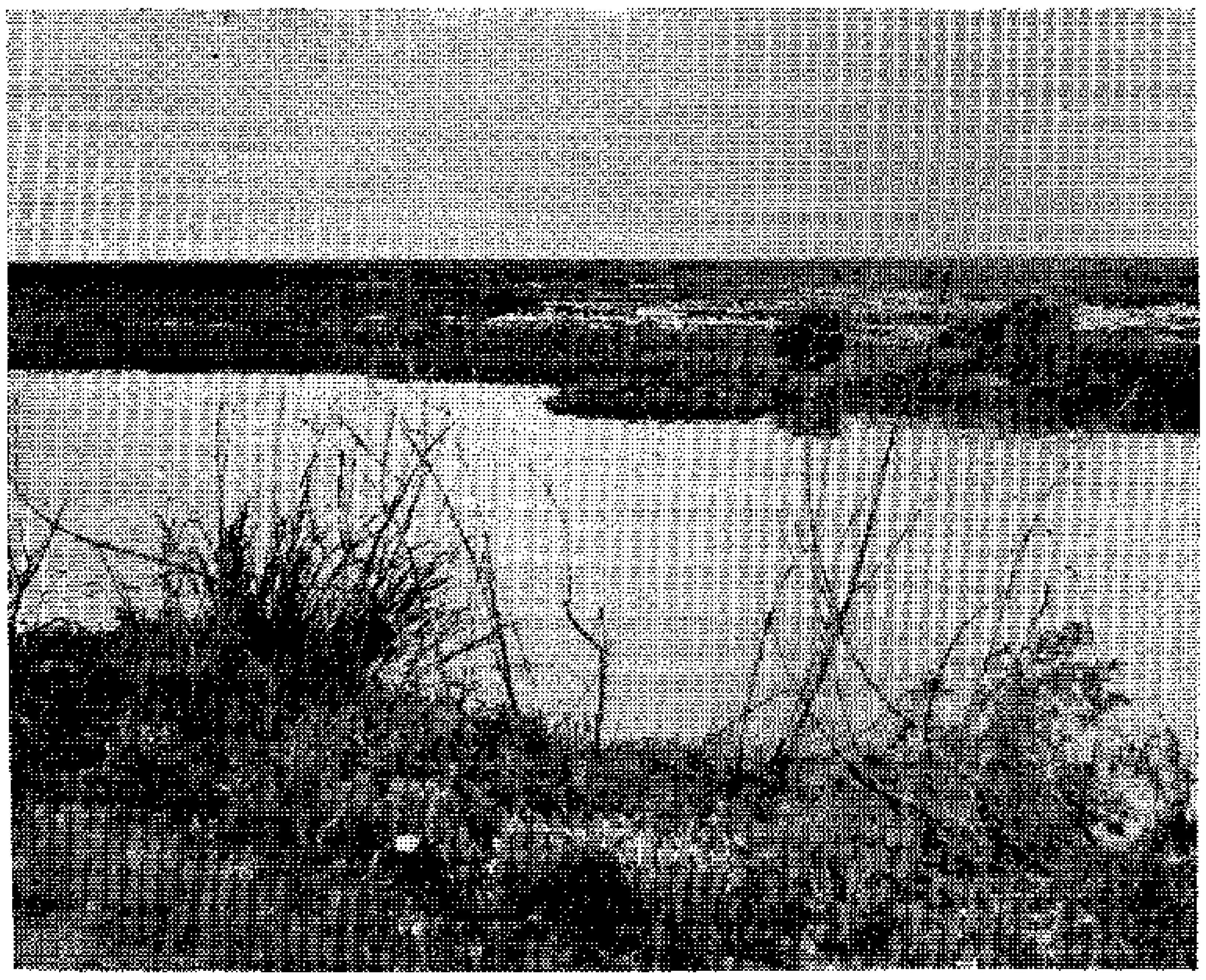

Figure 2. Salt marshes near Cameron, Louisiana. Marshes such as these extend into Texas and are rich storehouses for nutrients, vitamins, and organic detritus which are so vital in maintaining the estuarine habitat.

stirring much of their bottoms, redistributing nutrient materials.

Since the turbidity of Texas estuaries generally ranges from moderate to high, much of their volume does not receive the full effects of sunlight. Consequently, phytoplanktonic (floating plant) forms such as simple algae make up the bulk of the producers (organisms that synthesize protoplasm from inorganic compounds by photosynthesis) in estuarine waters, there being few submerged rooted aquatic plants. However, emergent plant growth of such forms as canes, rushes, and sedges, which constitute the dominant species of the salt marshes, is considerable in shallow waters relatively free of strong wave activity.

Salt marshes form much of the periphery of many northern Gulf estuaries, especially those east of the Sabine River (Fig. 2). They represent an ecotone between dry land and the low water level of the estuary. Many estuarine animals utilize portions of the marshes for feeding and nursery areas. Nutrient materials such as phosphates and nitrates which are vital in maintaining the estuarine community are flushed from the marshlands in large amounts by tidal action. Starr (1956, *Ecology* 37(4): 658-664) describes the importance of these areas for vitamin B_{12} production and many workers have shown this vitamin to be essential for growth of phytoplanktonic organisms.

Productivity in estuaries is often greater than that of open oceans and the continental shelf and frequently exceeds certain agricultural areas, grasslands, and shallow lakes (Table 1). Productivity is generally greatest during the summer months and daylight hours. Generally, primary consumers (herbivores or omnivores such as shrimp, filter-feeding mollusks, and certain fish) are more numerous in the estuary during the summer months. The addition of fertilizers, such as commercial preparations or sewage, can increase the rate of productivity, but frequently to the detriment of the community

TABLE 1

Distribution of primary gross productivity. The range of values found in major environments of the world (modified from Odum, 1959, Fundamentals of ecology, W. B. Saunders, Philadelphia, Table 8).

Types of ecosystems	Range of average gross productivity g./M²/day
Deserts and semiarid grasslands	Less than 0.5
Open oceans (probably also deep lakes)	Less than 1.0
Continental shelf ocean waters, shallow lakes and ponds, average forests, moist grasslands, and ordinary agriculture	0.5 to 5.0
Coral reefs, estuaries, some mineral springs, semiaquatic and terrestrial communities on alluvial plains, evergreen forests, and intensive agriculture	5.0 to 20.0
Maximum rates which may be maintained for short periods in the more productive natural and cultivated ecosystems (including polluted bodies of water)	Up to 60.0

in general if not properly planned. This will be discussed briefly in another section.

In shallow estuaries, changes in water temperature occur rapidly; summer temperatures as high as 38° C. and winter temperatures as low as 3° C. have been recorded in Galveston Bay by members of our laboratory staff. Changes of 20° F. (about 11.2° C.) within 5-day periods are common in the winter (Skud and Wilson, 1960, *Trans. Twenty-fifth N. Am. Wildl. Conf.*, p. 322-323), and Gunter (1941, *Ecology*, 22(2): 203-208) states that rapid drops in temperature—one as great as 40° F. within a 4-hour period—resulted in the death of millions of marine organisms.

Two basic salinity types are represented by inshore bodies of water surrounding the northern Gulf: (1) the hypersaline coastal lagoon in which salinity ranges upwards from the recognized 35‰[2] of standard sea water to 80‰ or higher, and (2) the estuary in which the salinity ranges from less than 1‰ at its headwaters to between 20‰ and 35‰ at its mouth. If the definitions given previously are to be followed, bodies of water belonging to the first group are not true estuaries even though they are frequently referred to as such; their high salinity values are generally due to small amounts of stream discharge coupled with high evaporation/precipitation ratios.

The inflow of fresh water is one of the principal sources of dissolved nutrients in Gulf estuaries. Freshwater discharge varies from practically none in the Laguna Madre with no permanent streams entering it, to the tremendous flow of the Mississippi River. Nash (1947, *J. Marine Res.*, 6(3): 169) states that the relationship of growth among estuarine phytoplankton—the basic producer of the estuarine habitat—to terrigenous nutrients is shown by their increase in numbers following periods of heavy rainfall.

In addition to nutrients carried to the estuary by tributary streams, tidal flow transports considerable amounts of organic detritus into the estuaries from ad-

[2]Salinity in parts per thousand is represented by the symbol ‰.

jacent marshes and marine minerals from the sea. Detritus is the principal food of many estuarine organisms. This material is also decomposed by bacteria and fungi, releasing in the process large amounts of organic and inorganic substances which are, in turn, absorbed by estuarine organisms via the aquatic medium.

THE ESTUARINE FAUNA

The estuarine ecotone or "buffer zone" between the fresh water of the river system and the salt water of the sea is a transition zone of tension, having sharp gradients in which outposts of the freshwater and oceanic animals —or communities of such—maintain themselves in environments that are increasingly unfavorable. Likewise, ecotones between dry land and the estuary proper—such as the salt marsh or bare beach—exist in varying proportions in Texas as one proceeds from Sabine Pass to the Rio Grande. Regardless of the form which the ecotone may assume, the tension encountered by an estuarine organism may result chiefly from its struggle with physical conditions and/or from direct competition with other species from one or both bordering communities. For example, at the border of a grassland community and a salt marsh, the grasses may compete directly with marsh reeds for sunlight, nutrients, and other necessities of life in such a manner that one plant type yields to the other. In such a situation and in areas where the controlling physical factors change rapidly, the transition between communities is usually abrupt and the zone narrow. In opposite circumstances, the transition between communities can be gradual and the zone wide.

In the ecotone, physical influences are different from, and usually intermediate between, those existing within either of the bordering communities. These or other conditions—food or shelter—may be superior in parts or all of an ecotone for certain species and, as a result, various kinds of plants or animals not occurring, or relatively rare, in the bordering communities may become abundant in the ecotone. For example, Ladd (1951, *Publ. Inst. Marine Sci.* 2(1): 137) and other workers found that the numbers of molluscan species is greater in parts of bays having salinity ranging between 15‰ and 31‰ than either in the Gulf (salinity over 32‰) or in portions of bays and headwaters having a salinity generally less than 15‰. This fact is referred to as the *principle of edges* (Clarke, 1954, Elements of ecology, John Wiley, N. Y., p. 412). Conservation officials and wildlife managers have become increasingly aware of this principle and are making efforts at increasing the amount of available ecotone having superior food, cover, and water since this usually favors increased populations of desired game birds and mammals. However, the area of estuarine and marshland ecotones is fixed and, unfortunately, is gradually being destroyed or altered to meet the needs of a growing population and an expanding industrial and agricultural economy.

All plants and animals tend to grow, reproduce and disperse until checked by some influence of the environment. The factor that first stops the growth or spread of an organism is called the *limiting factor*. This concept was first formulated by von Liebig as early as 1840 (1862, Die Chemie in ihrer Anwendung auf Agricultur und Physiologie, 7. Aufl., Friedrich Bieweg, Braunschweig, 2: 225) as the *"law" of the minimum* and was based on nutritional requirements of plants. Later workers have expanded the principle to include factors other than nutrients (heat, light, salinity, etc.) and to include the time element.

It should also be recognized that too much of a given factor can be just as limiting as too little. Consequently, the general principle of the law of the minimum was extended to include the maximum and was restated by Shelford (1913, Animal communities in temperate North America as illustrated in the Chicago region, Univ. Chicago Press, Chicago, p. 302-304) as the *law of toleration.* For greater clarity, this law may be restated in the following manner: as any environmental factor approaches either the upper or lower limit of toleration for a given species, that factor becomes of increasing importance in controlling the functioning, the growth, and even the existence of the individual members of the species.

Since organisms in the estuary are subjected to a continually fluctuating environment, they must possess wide tolerances, generally physiological or behavioral, to the factors involved. If they do not, they either perish or become reduced in numbers and/or restricted in distribution. Organisms lacking wide tolerances to environmental conditions are those affected most when adverse changes occur in the habitat.

In the estuary, salinity is an example of an environmental factor which restricts the distribution of animals, chiefly through interactions with physiological processes. Figure 3 shows a hypothetical relationship between three populations of organisms: two stenohaline (narrow tolerance range for salinity) and one euryhaline (wide tolerance range). The extent to which stenohaline organisms from either the fresh water or oceanic habitats can invade the estuary, and the ability of certain euryhaline species to permanently occupy the estuarine ecotone, depends upon the tolerance of each organism to variations in salinity. The physiological background of these problems is too complex to discuss here, but it can be found in many textbooks on comparative physiology.

Salinity not only directly affects estuarine animals, but indirectly as witnessed by studies on oyster mortality. High salinity alone does not cause death but permits

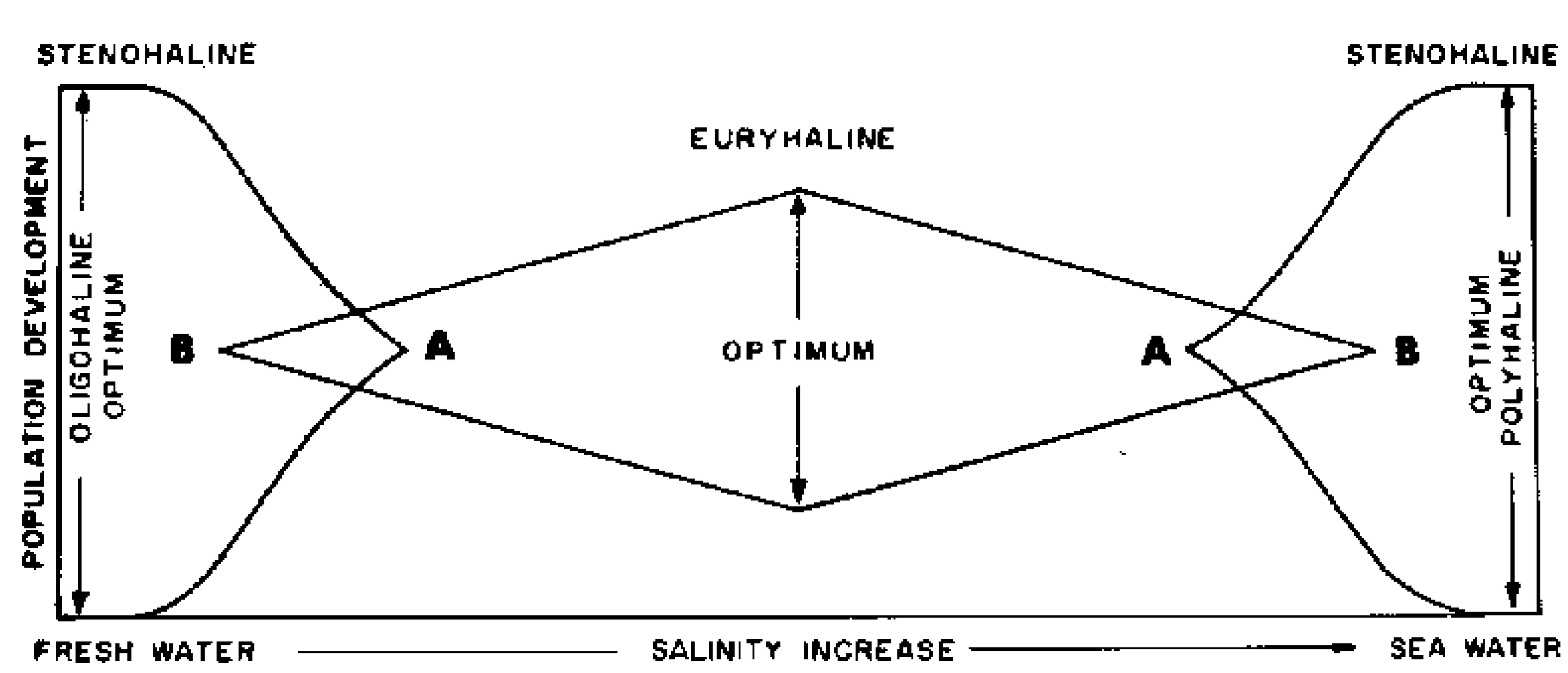

Figure 3. A schematic comparison of population development of stenohaline and euryhaline organisms. Minimum limits are shown by "A" and maximum limits by "B." Note that stenohaline organisms may be either low salinity tolerant (oligohaline) or high salinity tolerant (polyhaline), and that population development is often affected by slight changes in salinity (modified after Reid, 1961: Fig. 13.2).

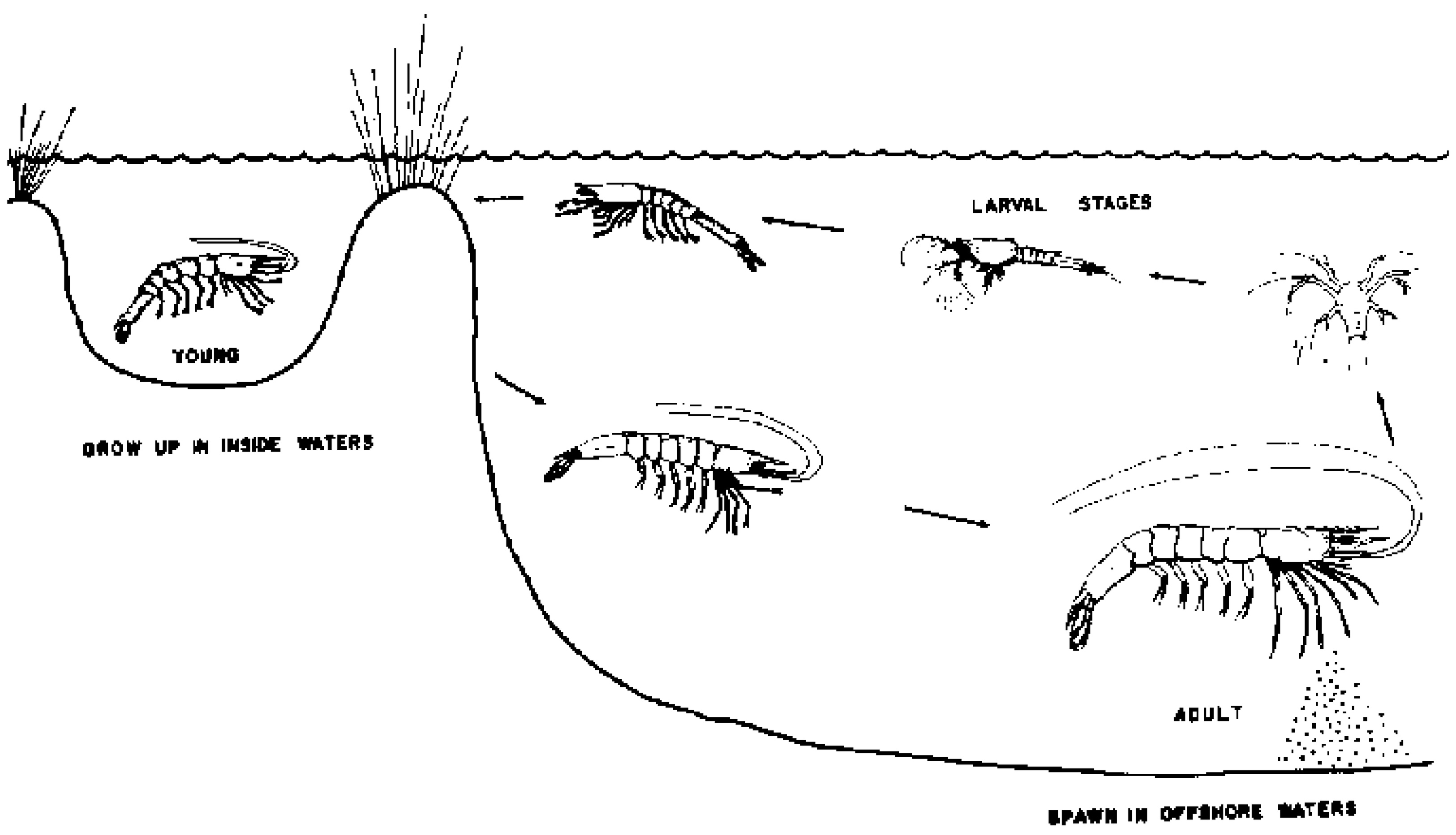

Figure 4. Generalized life cycle of the edible or commercial shrimp (Peaneus).

infestations and/or infections of shell pests, predators, parasites, and diseases. In moderately high salinity waters, the incidence of oyster mortality from these causes is much reduced. Thus, salinity *per se* does not appear to be the exclusive regulator.

Species found within the estuary can be separated into two general categories—incidentals and estuary-dependent. Incidentals are species from the fresh water or oceanic habitats which venture into the estuary either by accident or to feed for short periods and which then return to their original habitats or perish. Estuary-dependent species are those which utilize the estuary during part or all of their life cycles for such purposes as breeding, feeding, or developing into juveniles or subadults. This latter purpose is why estuaries are frequently referred to as "nursery grounds."

Skud and Wilson (1960: 321) state that the estuary-dependent species can be separated further into two basic categories—transients and residents. The majority of the more abundant forms are transients and are represented by fishes such as the menhaden *(Brevoortia)* and the mullet *(Mugil)* and by invertebrates such as the edible or commercial shrimp *(Penaeus)*. These particular species may be referred to as "semicatadramous" in that the adults spawn offshore and young move inshore to less saline waters. The oyster *(Crassostrea)* characterizes the residents which spend their entire lives within an estuary.

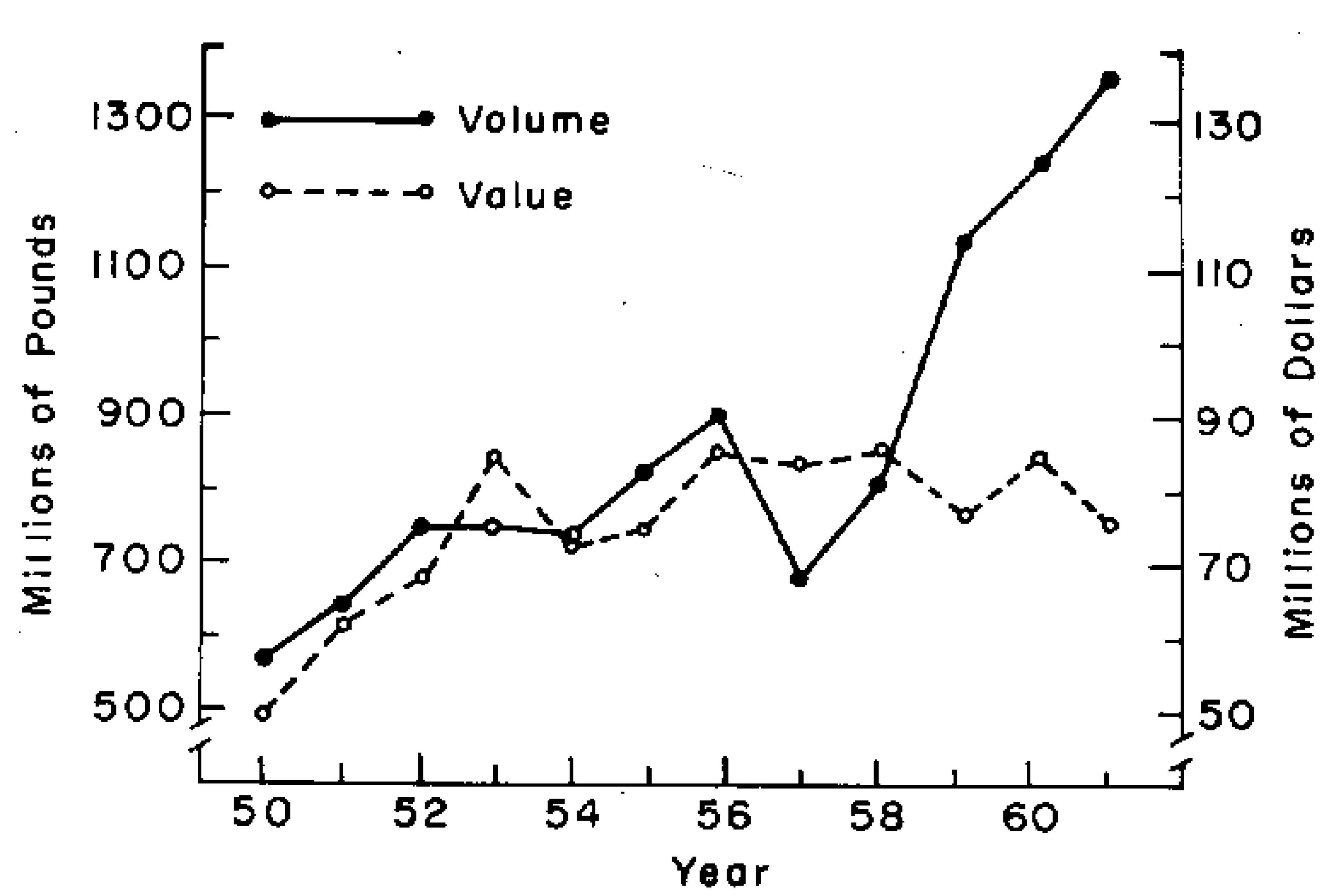

Figure 5. Gulf coast commercial fishery landings, 1950-61.

The life history of shrimp *(Penaeus)*, a typical transient, has been described in varying details by many workers, but the following outline should suffice for our purposes. Figure 4 shows the generalized life cycle of this shrimp. Adults spawn offshore and the postlarvae enter the estuaries through passes between the offshore bars and islands and move into the estuarine nursery areas. These nursery areas are frequently secondary or tertiary bays (as opposed to primary bays adjacent to the tidal passes), marshes, bayous, and tide-influenced portions of the large rivers. In a few weeks, following growth and development into juveniles or subadults, the shrimp migrate through the passes and return to the Gulf.

Like the brown shrimp, the life cycle of the oyster *(Crassostrea virginica)* has also been described by many workers. A resident species of the estuary, the oyster generally spawns in the bays during the warmer months. The eggs and larvae develop rapidly and within a few weeks must find a suitable surface for attachment. If successful, they become permanently attached adults. Due to its ability to withstand severe changes in environmental conditions, the oyster is a successful species in many Gulf estuaries.

The shrimp and the oyster present two greatly contrasting pictures with respect to salinity tolerance. The oyster, euryhaline throughout its entire life, is the opposite of the shrimp which is euryhaline during its life in estuarine waters and stenohaline for oceanic salinity during its adult and larval stages. There are, however, many individual and specific variations to this general scheme among the shrimp.

THE COMMERCIAL FISHERY

Data from the U. S. Fish and Wildlife Service's Statistical Digests for the 14-year period from 1950 through 1963 show that commercial fishing on the Gulf coast has undergone a tremendous expansion. Landings in the Gulf states have increased from a total of 570 million pounds with a value of $50 million in 1950, to over 1,377 million pounds representing a value of $76 million in 1961 (Fig. 5). In 1950, this fishery accounted for 11 and 14 percent of the total U. S. poundage and value, respectively, but increased to 26 and 20 percent for these respective items in 1961. Preliminary figures for 1963 are still higher, with yields totaling 1,387 million pounds valued at $99 million representing 29 and 26 percent, respectively, of the total poundage and value of the U. S. Harvest.

Texas landings paralleled the data for the Gulf coast during the same period (Fig. 6). Landings increased from 97 million pounds valued at $11 million in 1950 to over 203 million pounds valued at $24 million in 1961. The 1961 landings ranked Texas second only to Louisiana on the Gulf coast in terms of poundage, but first in value. During the same year, Texas ranked 10th nationally in poundage and 5th in value of the landings. This high rating in terms of value is due primarily to the large harvest of the brown shrimp. The first-place national ranking of Louisiana in terms of poundage is due to an increasing utilization of menhaden for oils and meals. Harvests of these and other species are expected to increase in the future.

The contribution of the estuaries to these valuable fisheries is well known. Estuary-dependent species account for approximately 98 percent by weight (Diener, 1963, *In* U. S. Fish and Wildl. Serv. Cir. 161, p. 52) and about 90 percent of the value (Skud and Wilson, 1960: 320) of Texas commercial landings. The vast majority of species represented in the commercial fishery are transients, the only resident of any significance is the oyster. The same generalization holds true for most sport fisheries in Texas coastal waters.

It should be emphasized that not all estuarine species enter the commercial fishery harvest. Many species occupying lower trophic levels of the various food chains, especially the herbivores, form the bulk of the diets of such sought-after species as the sand seatrout *(Cynoscion arenarius)* and the southern flounder *(Paralichthys lethostigma)* (Reid, 1955, *Texas J. Sci.* 7(4): 446, 448), and must, therefore, receive equal consideration with the commercially important forms.

MAN-MADE CHANGES

We have only briefly described the estuarine environment, its characteristics, its fauna, and the subsequent contribution of this fauna to the commercial fisheries of the Gulf coast, with especial reference to Texas. Many will probably ask, "What does all of this have to do with the central theme of this conference—'Water Quality and Chemicals: Industrial and Agricultural'?" The answer is this: a basic knowledge of estuarine biology is essential before we can understand the problems associated with maintaining suitable quality habitat in the estuary, particularly since this habitat is subject to alteration by reduction of fresh-water discharge and introduction of agricultural and industrial chemicals. The myriad of engineering projects in the estuaries and their watersheds further complicates the problem.

We do know that naturally occurring prenomena which alter the *status quo* of the estuarine ecotone, such as droughts, floods, rapid temperature changes, and hurricanes, frequently have adverse effects upon estuarine fauna. Some of these effects are often reproduced, though usually on a small scale, by man-induced alterations associated with a growing population and expanding economy.

The effects of such projects as impoundments and diversion channels on river basins draining into the estuaries and dredging and channelization in the estuaries themselves are many and varied. Even though the effects of these projects cannot always be accurately evaluated, several types of changes may be foreseen. One of the most obvious alterations of existing estuarine conditions is caused by the reduction of fresh-water discharge through greater consumptive water use and increased total evaporation, due to more exposed surface area in reservoirs. A reduced discharge of fresh water could alter the suitability of certain areas to fish and crustaceans by raising salinity; by varying salinity, circulation, and water interchange patterns; by draining surrounding marsh areas; by reducing silt loads and thus altering deposition rates; and by reducing inflow of terrigenous nutrient materials required for primary productivity. Controlled fresh-water discharge, on the other hand, may benefit the estuarine habitat by providing water at periods when it would most benefit the fauna or by leveling peaks and dips represented by flood and drought periods.

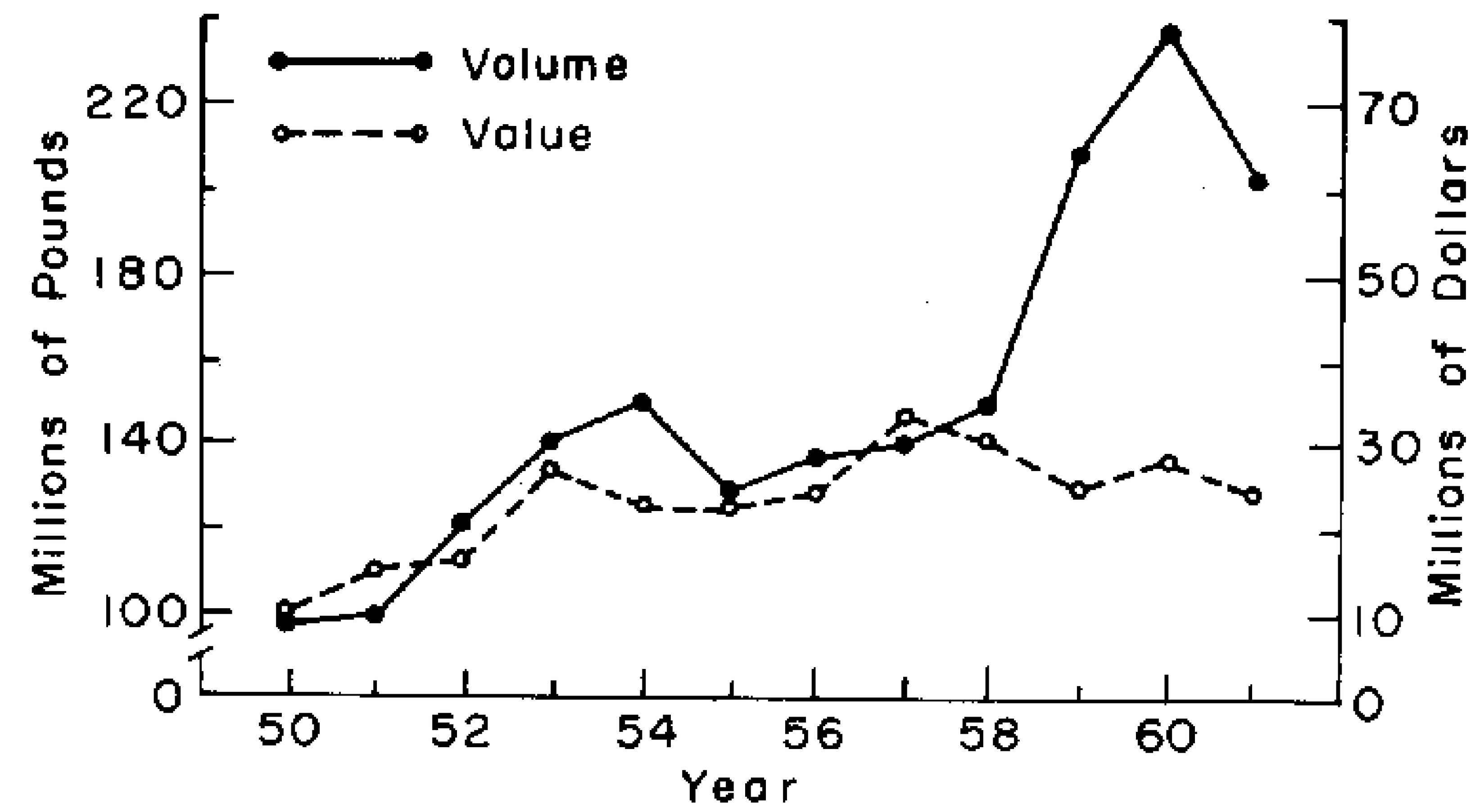

Figure 6. Texas commercial fishery landings 1950-61.

A further indication of an expanding economy along the Texas coast is the increasing number of navigation channels, oil wells and associated structures, and general construction projects which alter the quality of fishery habitat in the estuaries to varying degrees (Figs. 7, 8, 9).

Navigation projects, many of which are associated with the Gulf Intracoastal Waterway, often restrict water circulation and interchange by segmenting the estuary with channels and spoil banks. A physical loss of desirable habitat also occurs and resulting siltation can kill oysters by suffocating them. Channelization has become a major problem in Louisiana where alteration of natural drainage systems is facilitating salt-water intrusion and rapidly changing marshland ecology. This is a growing problem in Texas also. Channelization, unfortunately, includes not only dredging, but frequently realignments and repeated maintenance. Even so, with proper planning, adverse effects from channelization can usually be considerably reduced.

Oil wells and associated structures and general projects—a term embracing such items as small fills and bulkheads, wharf construction, pipeline crossings, loading facilities, etc.—usually have minimal effects

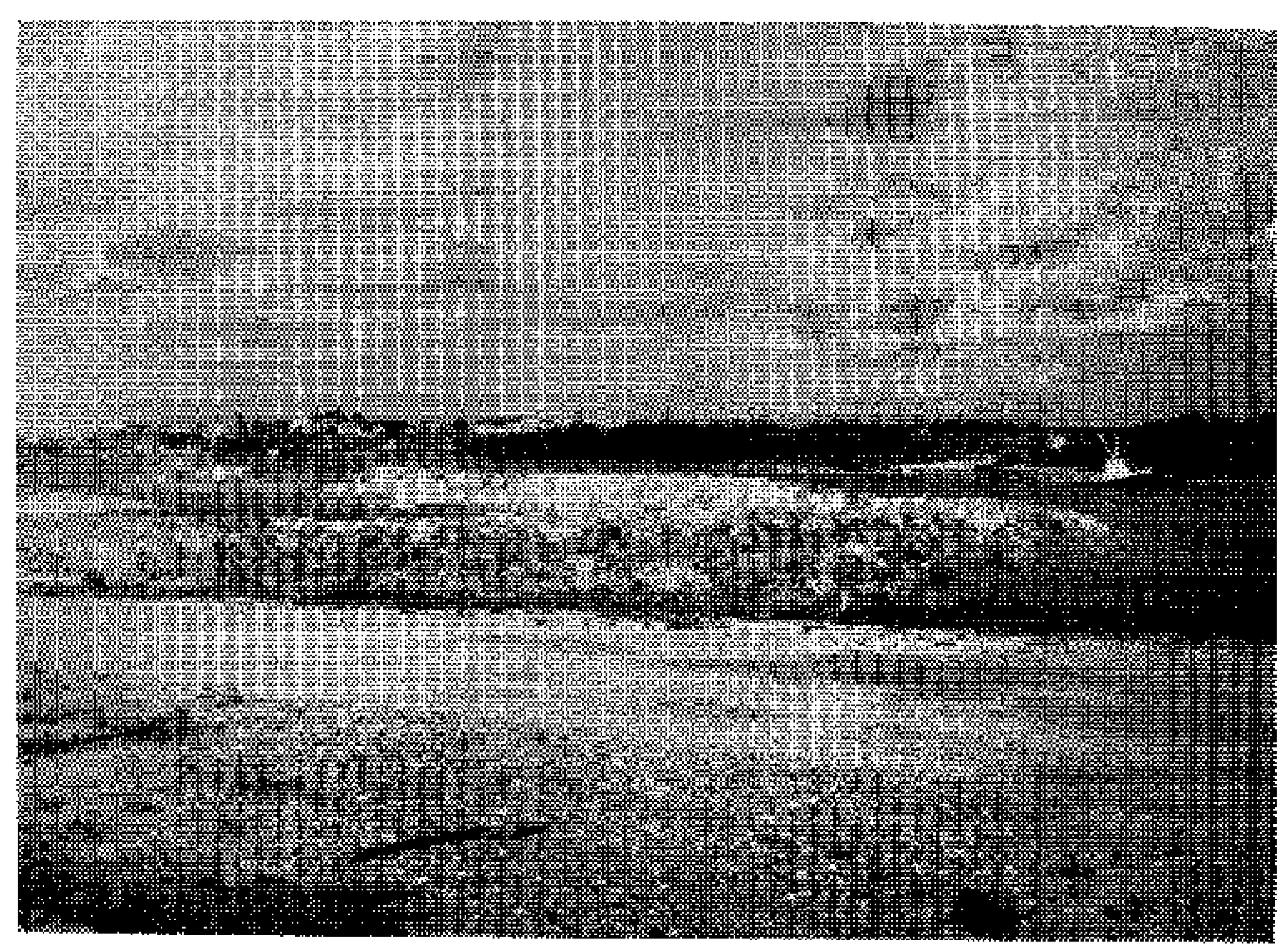

Figure 7. View of the Gulf Intracoastal Waterway near Aransas Pass, Texas. Channelization and the subsequent placement of spoil results in segmentation of the estuaries causing loss of habitat and alteration of water circulation.

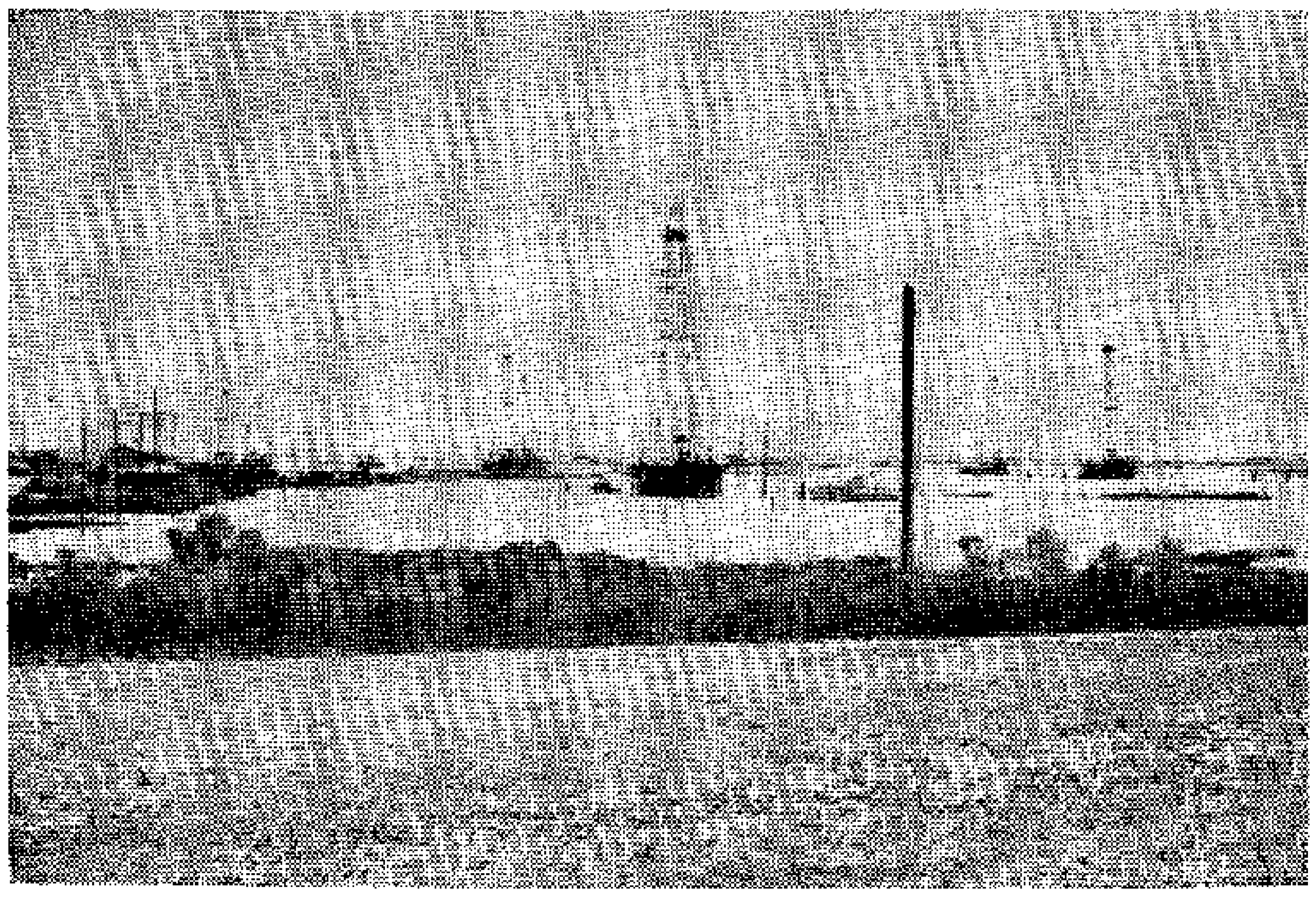

Figure 8. Oil field in Tabbs Bay, near Baytown, Texas. Oil wells are an example of several projects which, on an individual basis, have minimal effects upon the estuarine habitat, but which may produce serious cumulative encroachments when considered in large numbers.

upon the estuarine habitat when considered on an individual basis. In large numbers, however, they may produce serious cumulative encroachments upon valuable and irreplaceable estuarine habitat.

There is considerable irony associated with many of these small projects. Bulkheads and their fill, marinas, fishing piers, and other similar structures designed to facilitate the harvest of many species of fish and crustaceans by both commercial and sporting groups often alter or even destroy valuable bay bottom and shorelines used by these same species. Siltation resulting from improper shell dredging can also kill oysters.

What is being done to preserve our estuarine areas from damage caused by the smaller, but numerous projects? When such a project is to be built in navigable waters of the United States, the sponsor must obtain a Department of the Army Navigation permit from the Corps of Engineers. The Fish and Wildlife Coordination Act (48 Stat. 401, as amended; 16 U.S.C. 661 *et seq.*) provides the legal framework for the U. S. Fish and Wildlife Service to review such permit applications before construction. This same legislation also provides for the U. S. Fish and Wildlife Service to review all Federal water development projects.

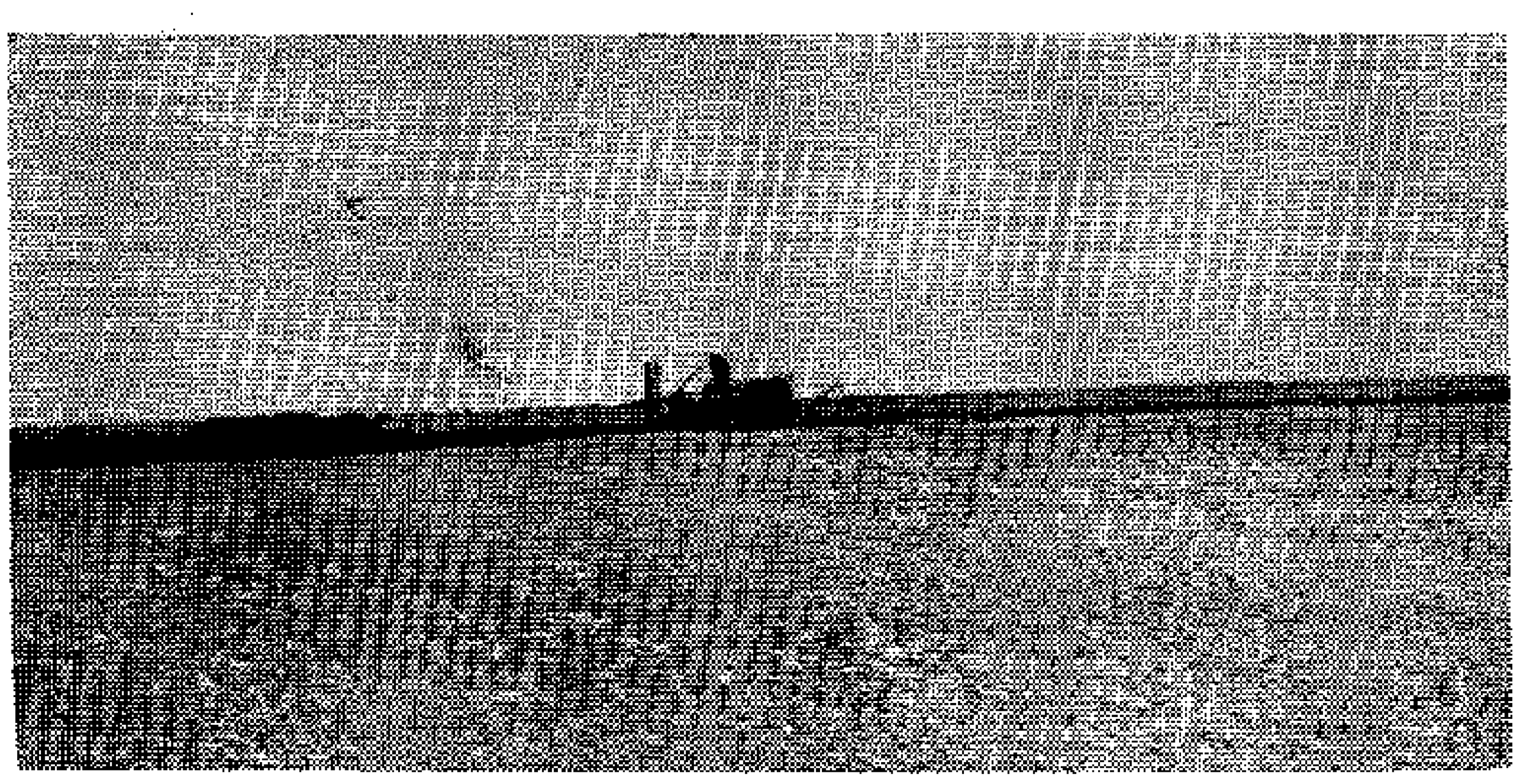

Figure 9. Shell dredging in Nueces Bay, Texas. Siltation from improper dredging operations can kill oysters.

The Branch of River Basin Studies of the Bureau of Sport Fisheries and Wildlife, working with the appropriate state conservation agencies and the Bureau of Commercial Fisheries whenever commercial fishery resources are involved, conducts surveys and prepares detailed reports on projects which could adversely affect fish and wildlife resources. These reports assess the fish and wildlife resources involved, the extent of potential project damage and frequently recommend measures that, if incorporated in a particular project, would eliminate or reduce anticipated damages. Occasionally, such measures actually benefit the resources.

It has been said that Texas, with its arid west supporting a predominately irrigation agriculture and its humid industrialized east, represents a microcosm in which the entire range of nationally important water problems occur (Kneese, 1963, *Proc. Eighth Ann. Conf. Water for Texas*, p. 7). As such, the problems of water supply are many and complex. Consequently, the Bureau of Reclamation's Texas Basins Project was developed.

The Texas Basins Project, presently in the planning stage, is an integral and significant segment of an overall state-wide water supply plan which would provide for developing and delivering adequate water to meet estimated municipal and industrial requirements in the year 2010 and to develop new irrigation with waters not otherwise utilized. The overall plan is basically the plan adopted by the U. S. Study Commission—Texas.

This important project includes proposals to construct numerous upland reservoirs as well as a water transport canal to divert the flow of principal streams in east and central Texas to semiarid portions of southern Texas. Such a plan would provide water for potential municipal, industrial, and irrigational demands, but would greatly reduce tributary discharge into most Texas estuaries and, unless modified, could adversely affect the quality of estuarine habitats. During drought years, this reduction could become critical, especially in view of other water demands which are expected in the future, since it is also apparent that nonproject reservoirs would divert much more water than the Texas Basins Project. Thus, the Texas Basins Project would, from the standpoint of lowering the quality of habitat for fishery resources, compound an already critical problem.

It is presently estimated that projects not associated with the Texas Basins Project will reduce the present average annual tributary discharge of 26.5 million acre-feet into Texas estuaries by about 35 percent by 2010. High salinities frequently found in the estuaries and Coastal lagoons of western and southern Texas would be found in many more estuaries of Texas and smaller harvest values per unit of area typical of those estuaries would be characteristic of many more.

The Texas Basins Project, unless modified, would further reduce tributary discharge which could result in additional losses to coastal fishery resources. Populations of shrimp, oysters, crabs, and several fishes would be subjected to a reduction in numbers and/or restriction of suitable habitat if not wholesale depletion in several estuaries during periods of drought.

The graduated reductions in fresh water would also be detrimental to various recreational fisheries since many sport fishes are estuarine-dependent and nearly all are transients.

The detrimental effects resulting from reduced tributary discharge could be intensified through the introduction of toxic pesticides and herbicides into the estuaries through return flows from adjacent irrigation units. These chemicals, the number of which is continually increasing, have many varied uses depending primarily on the types of undesirable animal or plant that is to be controlled or eradicated. Unfortunately, it is not known what types or in what quantities these chemicals will enter the estuaries.

Equally variable are their known effects on aquatic organisms. Some have been shown to have no effects on test organisms in the laboratory, while others are lethal to all organisms with which they come into contact. Still others show a toxicity to a given species or particular age groups within a given species. This is a field which is relatively unexplored and has many opportunities for both basic and applied research.

The problems posed by industrial and municipal wastes in the form of return flows are just as complex as those of pesticide and herbicide introduction. The problems in the future will be more vexing in that the quality of these return flows will generally be unknown. We do know what happens when treated or untreated sewage or certain industrial wastes are introduced to a body of water, usually fresh. We have seen that pollutants (especially sewage) increase primary productivity above normal levels (Table 1), which can be either beneficial or detrimental to the community as a whole. If too much sewage is added, primary productivity could assume great proportions known as "blooms" which are capable of altering the carbon dioxide and oxygen cycles within a community. Such a phenomenon has been known to result in large fish kills similar to those created by rapid temperature changes or by the toxins of the "red-tide" organism found in the Gulf of Mexico. Other wastes are capable of taking oxygen and other materials which are vital to the maintenance of the estuarine habitat from the water and forming new compounds, many of which have unknown properties.

At the present time, wastes are being dumped into small bodies of estuarine water such as Clear Lake north of Galveston, Texas. This body of water is extremely valuable as a nursery ground for commercial shrimp and as a feeding and nursery ground for many species of fish. With an increasing population, however, pollution has increased in recent years and several kills of menhaden have been reported. The condition of Clear Lake is expected to worsen as the population continues to increase.

A few of the more obvious methods of lessening the detrimental effects of these pollutants upon the estuaries appears to be diluting return flows with more water, treating the sewage and other wastes, and dispersing the wastes into larger bodies of water such as a large estuary or the Gulf of Mexico. Dilution of return flows, however, is not even now adequate in many areas, and, as the population expands, water which could be used for this purpose would be in still greater demand. The potentials offered in the future by desalinization of sea water —such a plant is now in operation at Freeport, Texas (Fig. 10)—may offer partial remedy.

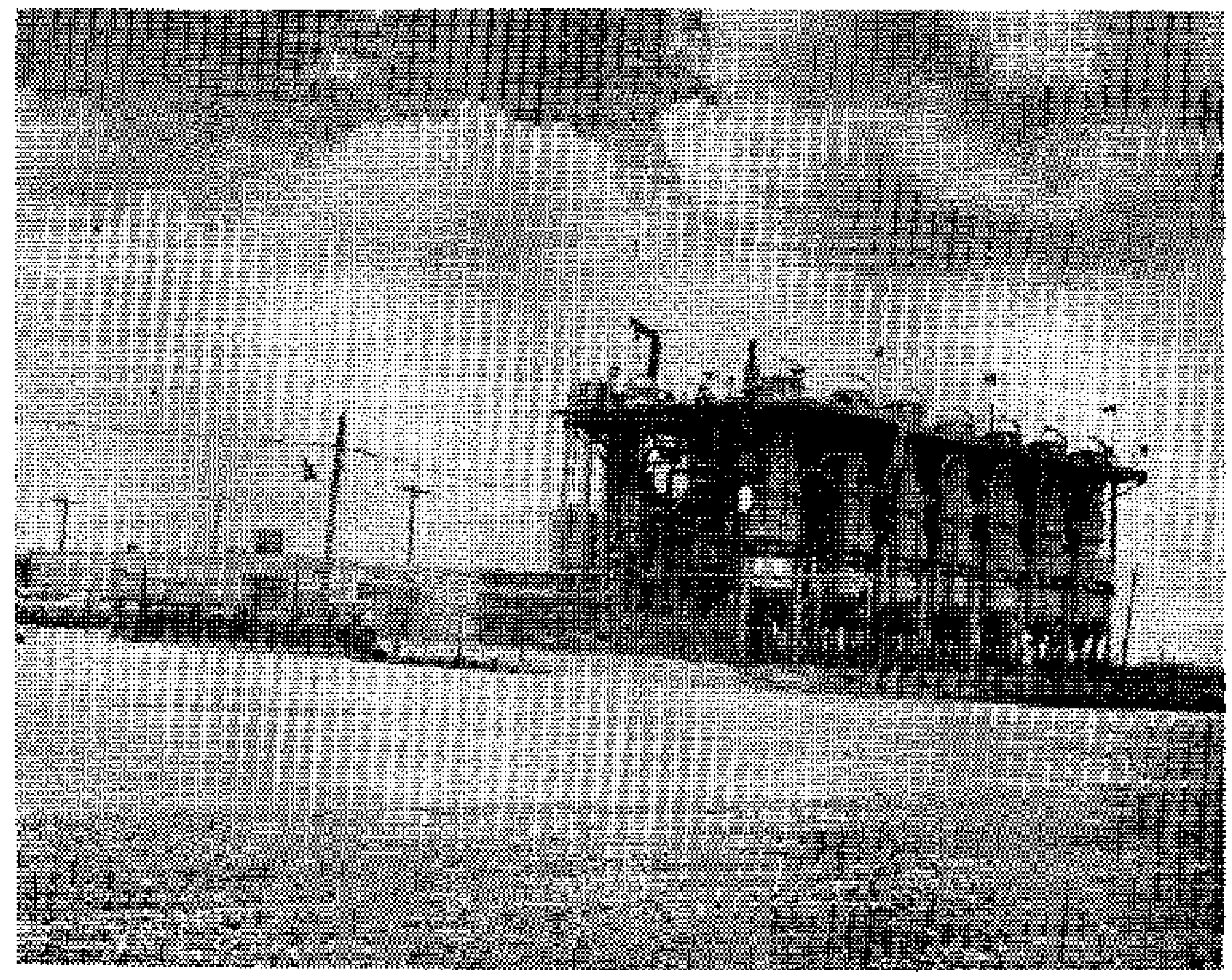

Figure 10. Desalinization plant at Freeport, Texas.

The other two methods could be costly. Altering the chemical properties of the return flow by the various users would require different methods of treatment and the cost of some could well be prohibitive. Dispersion of wastes into large bodies of water such as the Gulf of Mexico or, if properly regulated, open waters of Galveston Bay, might offer a solution. But the transport of wastes over a considerable distance would be prohibitive to all save large municipalities and industries or to those situated near these bodies of water. This method would, however, prevent the trapping of wastes in such limited areas as Clear Lake.

The maintenance of a suitable estuarine habitat is essential to the commercial and sport fisheries of Texas and the Gulf coast. Research must be continued and intensified in each of the estuaries in order to: (1) obtain a complete documentation of fishery resource values; (2) determine more exacting estimates of minimum natural fresh-water discharge requirements; (3) determine the most opportune time for release of fresh water should it not be available in sufficient quantities throughout the year; (4) determine if return flows, quality permitting, could partially replace direct tributary discharge; and (5) establish criteria to assist in developing plans to prevent losses in estuaries from pesticides and other pollutants. It is our hope that large water-development projects will become truly multi-purpose so as to consider all major national resources.

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